PIEPERPOWER

Understanding Electrical Power System Studies: A Foundation for Electrical Safety

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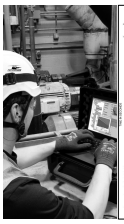

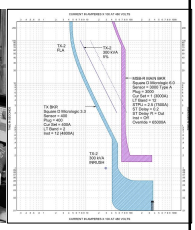

Wisconsin Safety Council 4-14-2026

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Purpose of an Electrical Power System Study

- Safety
- Electrical System Reliability
- Code Compliance

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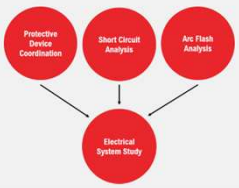
Electrical Power System Study



- Electrical One-line Drawings
- Short Circuit Analysis
- Protective Device Coordination Study
- Arc Flash Incident Energy Analysis

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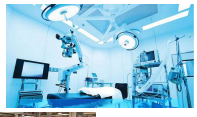

Where These Studies Are Required

- Industrial
- Healthcare
- Institutional
- Commercial
- Large Multifamily Residential Complexes

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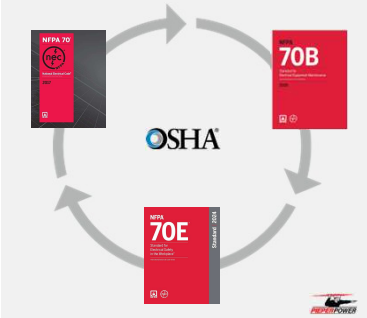
Codes & Standards

NFPA-70
Electrical Installation

NFPA-70B
Electrical Maintenance

NFPA-70E
Safe Work Practices

OSHA
Standard for Workplace Safety



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NFPA-70 National Electrical Code

ELECTRICAL INSTALLATION REQUIREMENTS

SHORT CIRCUIT REQUIREMENTS

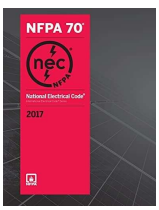
- Ensures equipment is rated to handle high current faults

PROTECTIVE DEVICE COORDINATION

- Ensures a selectively coordinated system

ARC FLASH WARNING LABELS

- Warns workers of potential arc flash hazards



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NFPA-70B Standard for Electrical Equipment Maintenance

TESTING & MAINTENANCE REQUIREMENTS

CHAPTER 6 | SINGLE-LINE DIAGRAMS AND SYSTEM STUDIES

- 6.2 Single Line Diagrams
- 6.3 Short Circuit Studies
- 6.4 Coordination Studies
- 6.7 Incident Energy Analysis (Arc-Flash Study)

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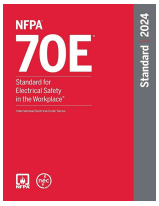
NFPA-70B Standard for Electrical Safety in the Workplace

- How to establish an Electrical Safety Program (ESP)
- Estimate likelihood and severity of potential arc flash
- How to establish an electrically safe work condition
- Determine necessary PPE
- Arc flash label requirements
- Electrical safety training requirements
- Electrical shock protection boundaries (based on voltage)
- Explains how energized work must be justified
- Lockout Tagout (LOTO)



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OSHA & NFPA 70E

SHALL

OSHA is Law

OSHA

HOW

How to comply with OSHA's electrical safety requirements

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OSHA Requirements

1910 SUBPART S | ELECTRICAL

1910.333 | GENERAL
Safety-related work practices shall be employed to prevent electric shock or other injuries resulting from either direct or indirect electrical contacts, when work is performed near or on equipment or circuits which are or may be energized.

1910.335(A)(1)(I)
Employees working in areas where there are potential electrical hazards shall be provided with, and shall use, electrical protective equipment that is appropriate for the specific parts of the body to be protected and for the work to be performed.

GENERAL DUTY CLAUSE
Each employer shall furnish to each of his employee's employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees.

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Electrical Power System Study Process

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Typical Power System Study Process

TURN-KEY STUDIES
(Existing Facilities)

- On-site data collection / Contact Utility
- Create One-line diagrams in power study software
- Perform protective device coordination, arc flash & short circuit calculations
- Provide recommendations and arc flash mitigation
- Apply arc flash labels, make breaker adjustments
- Meet with customer for closeout meeting
- Maintain the study when modifications are made

ELECTRICAL SYSTEM STUDIES
Design Build or Per Spec (New Installations)

- Contractor provides equipment data, submittals, and Utility info
- Create One-lines / Perform arc flash & short circuit calculations / Engineering work
- Provide preliminary report to order equipment.
- Finalize report to account for any changes during construction.
- Deliver labels, device settings, and final reports to contractor

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Data Collection

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Data Collection

- 1st step of any study
- Most time-consuming part of the study
- Licensed electrician safely opens panels and equipment
- Document the necessary information
  - Verify breakers and fuse size and info
  - Verify wire sizes and lengths
  - Trace out necessary circuits to locate all significant equipment
  - Document data for motors, transformers, generators, etc.

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Data Collection

- Typically performed during normal business hours while energized
- Reference preventive maintenance test reports
- May perform an IR scan while the equipment is open
- Point out electrical safety concerns
- Contact the electric utility company for fault current information

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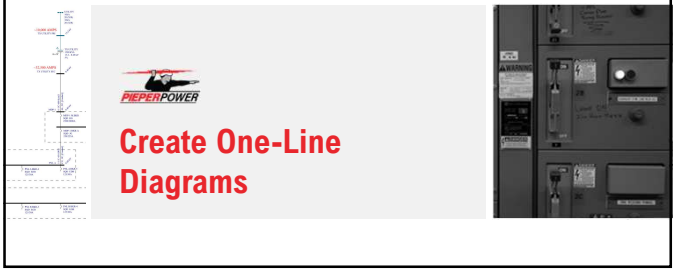

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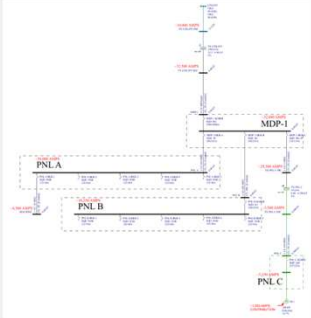
One-Line Diagrams

- Model the one-lines in the latest power system software
- Enter all data collected in the field
- Note any code violations found
- Enter Utility fault current data
- Set up multiple scenarios
- After one-lines are modeled, various studies may be performed



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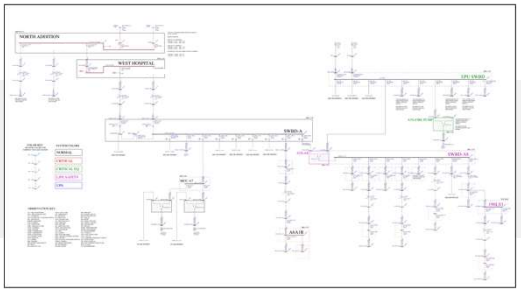
One-Line Diagrams



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Short Circuit Analysis

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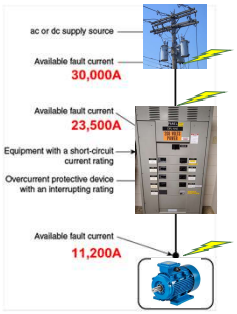
Short Circuit Analysis



What is Short Circuit Current / Fault Current ?

- The current delivered at a point on the system during a short circuit condition.
- Available Fault Current must be calculated. (The largest amount of current capable of being delivered at a point during a short circuit condition)
- **2020 NEC has changed "Short-Circuit Current" to "Fault Current".**

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Short Circuit Analysis

WHAT IS A SHORT CIRCUIT ANALYSIS?

- Using the one-line model, it will calculate the amount of current capable of being delivered at any point in an electrical system during a short circuit condition.
- Short Circuit study begins at the utility connection or other energy source such as solar or wind.
- Necessary to perform protective device coordination study and arc flash analysis.
- Evaluates the short circuit ratings of
  - Circuit Breakers
  - Fuses
  - Control Panels and equipment

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Short Circuit Analysis

WHY A SHORT CIRCUIT ANALYSIS IS REQUIRED

- Ensure equipment is rated to handle a high current fault
  - Equipment may fail and even explode if subject to short circuit current over its rating
- Required to meet several NEC code articles, and required by OSHA
  - Breakers, fuses, and control cabinets must all be rated to handle the available fault current
- Needed to perform protective device coordination
  - To ensure that there is coordination for all fault levels
- Needed for arc flash calculations
  - Directly affects the arc magnitude and breaker or fuse opening time

IT ALL COMES DOWN TO SAFETY!

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Short Circuit Analysis

WHY IS A SHORT CIRCUIT ANALYSIS REQUIRED?

VIDEO

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Short Circuit Analysis

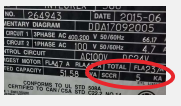
SHORT CIRCUIT CURRENT RATING

NEC 2017

110.10 Circuit Impedance, Short Circuit Current Ratings, and Other Characteristics
The overcurrent protective devices, the total impedance, the **equipment short-circuit current ratings**, and other characteristics of the circuit to be protected shall be selected and coordinated to permit the circuit protective devices used to clear a fault to do so without extensive damage to the electrical equipment of the circuit. This fault shall be assumed to be either between two or more of the circuit conductors or between any circuit conductor and the equipment grounding conductor.

OSHA STANDARD

1910.303(b)(5)
Circuit impedance and other characteristics. The overcurrent protective devices, the total impedance, the component short-circuit current ratings, and other characteristics of the circuit to be protected shall be selected and coordinated to permit the circuit protective devices used to clear a fault to do so without the occurrence of extensive damage to the electrical components of the circuit. This fault shall be assumed to be either between two or more of the circuit conductors, or between any circuit conductor and the grounding conductor or enclosing metal raceway.



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Short Circuit Analysis

SHORT CIRCUIT CURRENT RATING

The Available Fault Current is to be calculated at the following equipment;

110.24 SERVICE ENTRANCE EQUIPMENT
- Documented and made available to AHJ & **Field Marked**

409.22 INDUSTRIAL CONTROL PANELS
- Documented and made available to AHJ

430.99 MOTORS, MOTOR CIRCUITS, AND CONTROLLERS (MCCS)
- Documented and made available to AHJ

440.10 AIR-CONDITIONING AND REFRIGERATION EQUIPMENT
- Documented and made available to AHJ

620.51(D)(2) ELEVATORS
- **Field Marked**

670.5 INDUSTRIAL MACHINERY
- **Field Marked**

NEC 2023 Requires the fault current to be **calculated and field marked** on Switchboards, Switchgear, and Panelboards.

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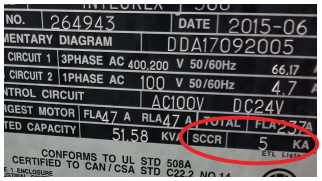
Short Circuit Analysis

SHORT CIRCUIT CURRENT RATING

- What is the inspector looking for?
- Who is responsible for ordering the proper SCCR?
- Industrial machinery electrical panel installers are required to verify the available fault current at their customer facilities.



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Short Circuit Analysis

INTERRUPTING RATING

NEC 2017

110.9 Interrupting Rating
Equipment intended to interrupt current at fault levels shall have an interrupting rating at nominal circuit voltage at least equal to the current that is available at the line terminals of the equipment. Equipment intended to interrupt current at other than fault levels shall have an interrupting rating at nominal circuit voltage at least equal to the current that must be interrupted.

OSHA

OSHA STANDARD 1910.303

1910.303(b)(4) Interrupting Rating
Equipment intended to interrupt current at fault levels shall have an interrupting rating sufficient for the nominal circuit voltage and the current that is available at the line terminals of the equipment. Equipment intended to interrupt current at other than fault levels shall have an interrupting rating at nominal circuit voltage sufficient for the current that must be interrupted.

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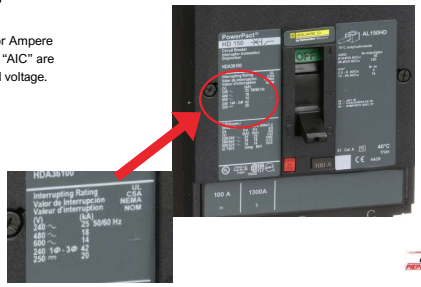
Short Circuit Analysis
INTERRUPTING RATING

Interrupting ratings, or Ampere Interrupting Capacity "AIC" are based on the nominal voltage.

- 240V - 25kA
- 480V – 18kA
- 600V – 14kA



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Short Circuit Analysis
INTERRUPTING RATING

Why pay for a **65kA** rated breaker when an **18kA** breaker will suffice?

We can do a preliminary short circuit analysis to determine exactly what the required interrupting ratings should be at each panel.

HJA 100A
65kA @480V
$2,225

OR

HDA 100A
18kA @480V
$1,361

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Short Circuit Analysis

Equipment Duty Report
EasyPower 10.4.1.8349 6/25/2021 12:34:13 PM C:\...\Example Oneline.dez
EasyPower LLC.
Comments :
Page 1 of 1

3PH- 3-Phase Fault | 1PH-3W: LN Fault | 1PH-2W Line-to-Neutral: LN Fault | 1PH-2W Line-to-Line: DLG Fault
Vpu: 1.00

Bus		Equipment				Ratings	Duties		Comments
Name	Base kV	ID	Manufacturer	Style	Test Standard	1/2 Cycle (kA)	1/2 Cycle (kA)	1/2 Cycle Percent	
MDP-1	0.480	MDP-1 M.BKR	SQD	RG	ANSI-SYM	35.000	33.225	-6.1% Warning	
MDP-1 BUS	0.480	MDP-1 BKR-A	SQD	JG	ANSI-SYM	35.000	33.290	-4.9% Warning	
		MDP-1 BKR-B	SQD	JG	ANSI-SYM	35.000	33.290	-4.9% Warning	
		MDP-1 BKR-C	SQD	RG SP	ANSI-SYM	35.000	33.799	-4.3% Warning	
PNL A	0.480	PNL A.BKR-5	SQD	EDB	ANSI-SYM	18.000	32.800	82.2% VIOLATION	
		PNL A.BKR-4	SQD	EDB	ANSI-SYM	18.000	32.800	82.2% VIOLATION	
		PNL A.BKR-3	SQD	EDB	ANSI-SYM	18.000	32.800	82.2% VIOLATION	
		PNL A.BKR-2	SQD	EDB	ANSI-SYM	18.000	32.800	82.2% VIOLATION	
		PNL A.BKR-1	SQD	EDB	ANSI-SYM	18.000	32.800	82.2% VIOLATION	
PNL B	0.480	PNL B.M.BKR	SQD	JG	ANSI-SYM	35.000	10.223	-70.8%	
PNL B BUS	0.480	PNL B.BKR-5	SQD	EGB	ANSI-SYM	35.000	10.088	-71.2%	
		PNL B.BKR-4	SQD	EGB	ANSI-SYM	35.000	10.088	-71.2%	
		PNL B.BKR-3	SQD	EGB	ANSI-SYM	35.000	10.088	-71.2%	
		PNL B.BKR-2	SQD	EGB	ANSI-SYM	35.000	10.088	-71.2%	
		PNL B.BKR-1	SQD	EGB	ANSI-SYM	35.000	10.088	-71.2%	
PNL C	0.208	PNL C M.BKR	SQD	QB	ANSI-SYM	10.000	4.004	-59.9%	

NEC 110.9 Violation

OSHA 1910.303(b)(4) Violation

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Short Circuit Analysis
WHAT MAY HAPPEN IF NOT PERFORMED

- **Equipment may not be able to withstand a high current fault.**
  - Possible fire/equipment damage
  - Risk of injury
  - Unplanned down time.
- **Failed electrical inspection due to the following;**
  - Insufficient breaker kAIC ratings
    - Breakers need to be replaced ($$$)
  - Insufficient short circuit current ratings (SCCR) of equipment (Such as RTUs)
    - Equipment manufacturer may need to increase SCCR ($$$)
    - Electrical contractor may need to add impedance to the circuit (Longer wire, isolation transformer=$$$)

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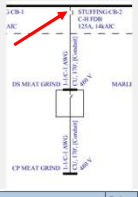
Short Circuit Analysis

REAL WORLD EXAMPLE



- 125A Breaker burned up when attempting to clear a fault at a downstream disconnect.
- Breaker rated for 14kA, in a panel with the available fault current of approx. 21kA
- This is a code violation and safety hazard. (NEC 110.9)

Bus		Equipment				Ratings	Duties		Comments
Name	Base kV	ID	Manufacturer	Style	Test Standard	1/2 Cycle (kA)	1/2 Cycle (kA)	1/2 Cycle Percent	
PNL STUFFING RM MEZZ	0.480	STUFFING CB-4	Cutler Hammer	EHD	ANSI-SYM	14.000	20.834	48.5%	VIOLATION
		STUFFING CB-5	Cutler Hammer	EHD	ANSI-SYM	14.000	20.834	48.5%	VIOLATION
		STUFFING CB-1	Cutler Hammer	FDB	ANSI-SYM	14.000	20.834	48.5%	VIOLATION
		STUFFING CB-9	Cutler Hammer	EHD	ANSI-SYM	14.000	20.834	48.5%	VIOLATION
		STUFFING CB-8	Cutler Hammer	FD	ANSI-SYM	14.000	20.834	48.5%	VIOLATION
		STUFFING CB-2	Cutler Hammer	FDG	ANSI-SYM	14.000	20.834	48.5%	VIOLATION
		STUFFING CB-10	Cutler Hammer	HFD	ANSI-SYM	65.000	20.834	47.8%	
		STUFFING CB-3	Cutler Hammer	EHD	ANSI-SYM	14.000	20.834	48.5%	VIOLATION

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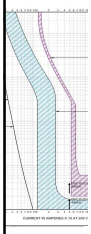

Protective Device Coordination

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Protective Device Coordination

WHAT IS A PROTECTIVE DEVICE COORDINATION STUDY?

- Evaluate breaker and relay settings to determine the ideal settings
- Create Time Current Curves (TCCs) in the power study software
- Modify settings in the software to visually verify level of coordination
- Utilize manufacturer's coordination tables
- Modify relays or breaker settings on site

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Protective Device Coordination

WHY IS IT SO IMPORTANT?

- Required by the NEC for Healthcare and Emergency electrical systems
- Ensure that circuit breaker or fuse closest to the fault opens before the upstream devices
- Ensure that critical equipment will remain energized
- Prevent unnecessary or unplanned downtime
- Prevent blackout condition for the rest of the electrical distribution
- Lower arc flash incident energy levels where possible

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Protective Device Coordination

WHERE PROTECTIVE DEVICE COORDINATION IS REQUIRED (2017 NEC)

- 517.31 Health Care
  - Essential Electrical System (Equip. Branch, Critical Branch, Life Safety)
- 620.62 Elevators
- 700.32 Emergency Systems
- 701.32 Legally Required Standby Systems
- 708.54 Critical Operations Power Systems

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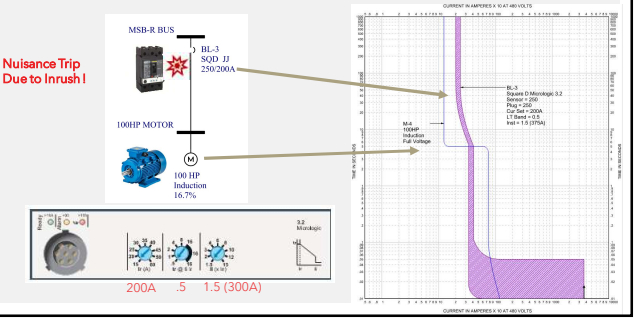
Protective Device Coordination

Nuisance Trip
Due to Inrush !



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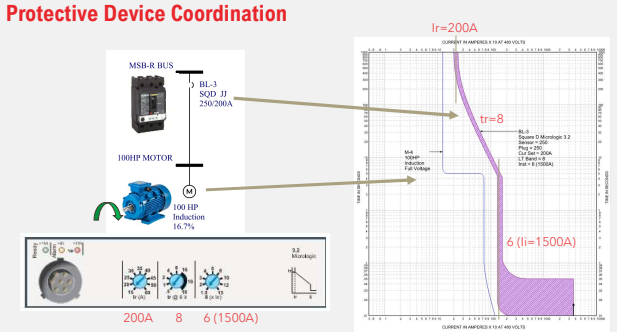
Protective Device Coordination



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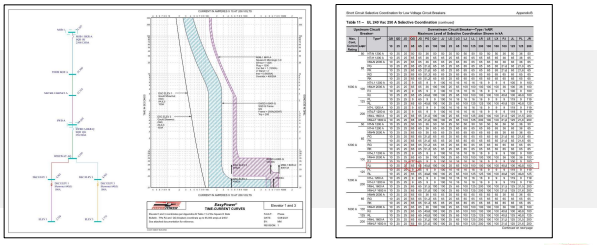
Protective Device Coordination

HOW TO ACHIEVE SELECTIVE COORDINATION



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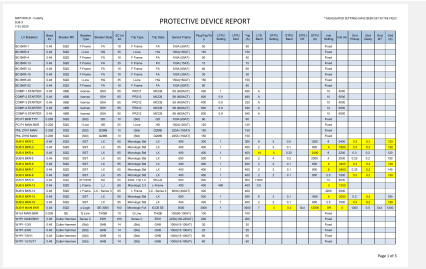
Protective Device Coordination

STANDARD DELIVERABLES

- Provide spreadsheet with breaker, relay, & fuse information
- Provide recommended settings


PROTECTIVE DEVICE REPORT

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Protective Device Coordination

HOW TO ACHIEVE SELECTIVE COORDINATION

- **Set breakers and relays PRIOR to energizing!**
  - Ensure there are no nuisance trips
  - Adjust settings with no arc flash or shock hazard
- Example – 4000A Main Breaker set to 1600A from factory
- Example – 60hp motor shorted to ground, tripped 1200A Main, not the local 100A breaker. Blackout condition for entire building.

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Protective Device Coordination

WHAT MAY HAPPEN IF NOT PERFORMED or NOT PERFORMED PRIOR TO CONSTRUCTION

- Life Safety and Emergency Systems may not selectively coordinate.
  - Loss of lighting
- Unexpected shut down of equipment
  - Interruption of process
- Construction delays – Failed electrical inspection
  - New breakers or fused panels may need to be installed ($$$)
  - Rework the Life Safety or Emergency feeders / equipment ($$$)

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Arc Flash Incident Energy Analysis

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Arc Flash Incident Energy Analysis

WHAT IS AN ARC FLASH ANALYSIS?

- Using the power study model, calculate the arc flash incident energy and arc flash boundaries.
- Provide mitigation recommendations
- Print and apply arc flash labels to equipment
- Update the study and labeling when significant changes are made, **not to exceed 5 years**
- Maintain the study and labeling for future updates

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Arc Flash Incident Energy Analysis

WHY IS AN ARC FLASH ANALYSIS SO IMPORTANT?

- Identify the potential arc flash and electrical shock hazards
- Determine the required arc rated PPE
- Determine the safe work boundaries to keep unprotected people safe
- Necessary for an arc flash and electrical shock risk assessment

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Arc Flash Incident Energy Analysis

EMPLOYER'S RESPONSIBILITIES

- Provide arc flash / lockout-tagout training
- Establish an Electrical Safety Program (ESP)
- Audit the ESP, Field Work, LOTO Program
- Provide necessary forms
  - Energized work permit
  - Arc flash risk assessment
  - Shock risk assessment
- Provide necessary PPE to qualified employees
- Maintain the arc flash and power study

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Arc Flash Incident Energy Analysis

REQUIREMENTS PERTAINING TO ARC FLASH

NEC 2017 | ARTICLE 110 REQUIREMENTS FOR ELECTRICAL INSTALLATIONS

110.16 Arc-Flash Hazard Warning

General. Electrical equipment, such as switchboards, switchgear, panelboards, industrial control panels, meter socket enclosures, and motor control centers, that is in other than dwelling units, and is likely to require examination, adjustment, servicing, or maintenance while energized, shall be field or factory marked to warn qualified persons of potential electrical arc flash hazards. The marking shall meet the requirements in 110.21(B) and shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

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NFPA-70E 2024

CHOOSE 1 OF 2 METHODS TO DETERMINING THE REQUIRED ARC RATED PPE

ARC FLASH PPE CATEGORY METHOD

- Use NFPA-70E Table 130.7(C)(15)
  - Based on Equipment and Voltage
- May NOT be used if certain parameters are not met (Read the fine print)

OR

INCIDENT ENERGY ANALYSIS METHOD

- Refer to the arc flash incident energy on the arc flash label
- PPE must meet or exceed cal/cm²

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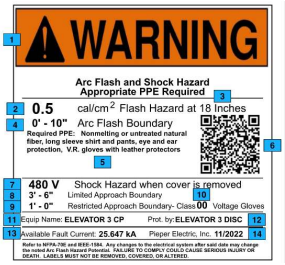
Arc Flash Incident Energy Analysis
SAMPLE ARC FLASH LABEL



1. **Warning Banner** - ANSI standard orange for a warning.
2. **Arc Flash Incident Energy** - This is the amount of heat energy (stated in calories/cm²) that personnel may be exposed to in the event of an arc flash. This is calculated at the specified working distance. The worker must wear arc rated PPE that is equal to or greater than the calculated incident energy.
3. **Working Distance** - The distance at which the incident energy is calculated. (Will change based on voltage.)
4. **Arc Flash Boundary** - This is the 1.2cal boundary, where unprotected skin may receives a 2nd degree burn. The distance at which you must put up barricades to keep unprotected personnel away, unless the limited shock approach boundary is greater.
5. **Required PPE** - PPE required by NFPA-70E, based on the calculated Incident Energy. Must be Arc Rated (AR) over 1.2cal/cm².
6. **QR Code** - When scanned, this will display the most recent one-line drawings in PDF format. Stored in the Pieper Dropbox.
7. **Electric Shock Hazard** - Nominal line-line, or worst case voltage within the equipment.
8. **Limited Approach Boundary** - The closest distance an unqualified worker may approach the equipment when there are exposed live parts. This is the distance to put up barricades to keep unprotected personnel out (unless the arc flash boundary is greater)
9. **Restricted Approach Boundary** - The closest distance a qualified worker can get to exposed live parts without proper Voltage Rated gloves and voltage rated tools.
10. **Voltage Rated Glove Class** - Minimum voltage rated glove class that is required based on the maximum voltage when there are exposed live parts within the restricted approach boundary.
11. **Equipment Name** - Specific name of the equipment that the labels is applied to, and as found on the one-line drawings.
12. **Protected By Name** - Upstream protective device that the arc flash incident energy is calculated from
13. **Available Fault Current** - The largest amount of current capable of being delivered at a point on the system during a short circuit condition. Equipment must be rated equal to or greater than the available fault current.
14. **Date** - The date the label was printed.

Based on the 2024 version of NFPA-70E 4/30/2025

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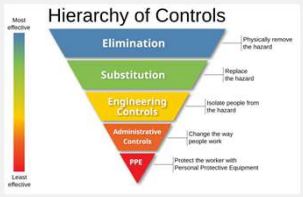
Arc Flash Incident Energy Analysis
HOW TO PREVENT ARC FLASH INCIDENTS



- Do not work energized!
- Utilize absence of voltage testers
- Perform Mitigation to reduce the hazard
- Keep arc flash in mind when designing or installing electrical equipment
- Train your employees

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Arc Flash Incident Energy Analysis
ARC FLASH MITIGATION

- Install faster acting fuses
- Modify breaker settings
- Utilize remote switching devices
- Isolate line side of breakers
- Install absence of voltage testers
- Install IR windows

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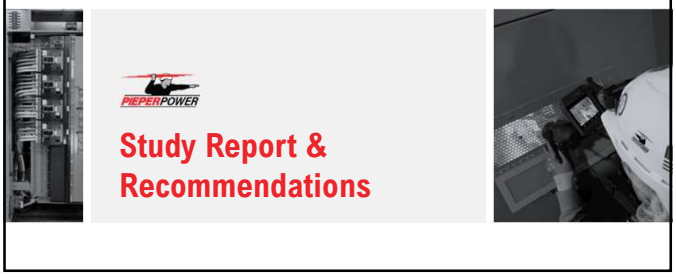
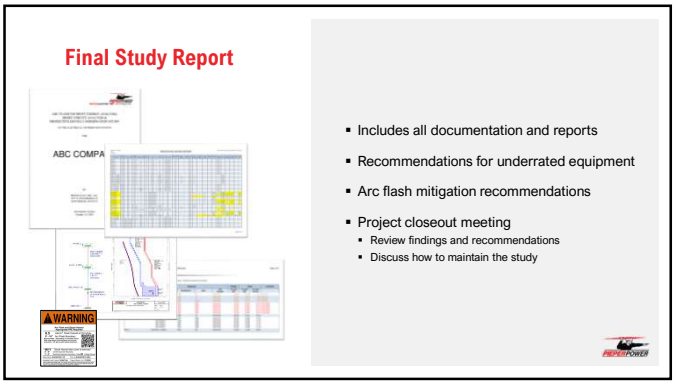
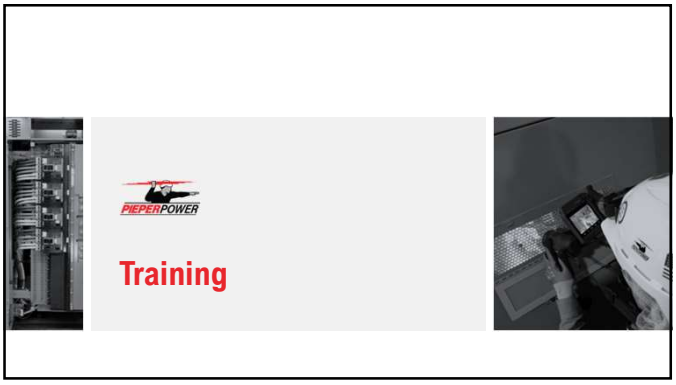

Study Report &
Recommendations

52


Final Study Report
ABC COMPA
WARNING
Includes all documentation and reports
Recommendations for underrated equipment
Arc flash mitigation recommendations
Project closeout meeting
Review findings and recommendations
Discuss how to maintain the study

53


Training

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Training Requirements

- Electrical Safety Training
  - Train employees exposed to an electrical hazard
  - Train to identify and understand the hazards
  - How to select and wear necessary PPE
  - Not to exceed 3 years
  - Shall be documented
- Lockout-Tagout Training
  - Employees involved in lockout/tagout procedures
  - Not to exceed 3 years
  - Shall be documented
- Emergency Response Training
  - Employees exposed to electric shock hazards and those who are responsible for the safe release of victim shall be trained in methods of safe release
  - Refresher training to occur annually
  - Shall be documented

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NFPA-70B Standard for Electrical Equipment Maintenance

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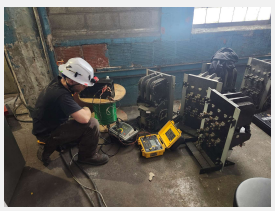
Preventive Maintenance
NFPA-70B Compliance

- Required by NFPA-70B
- Intervals depend on equipment type and condition
- Identifies issues prior to failure.



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Preventive Maintenance

WHY PERFORM ROUTINE MAINTENANCE PER NFPA-70B?

- Protect personnel and equipment
- Avoid unplanned / costly downtime
- Ensure electrical system reliability

$13,900,000 – Breaker Explosion Case Settles

Pennsylvania – Oct 2009

An industrial software technician who suffered serious burns in a plasma explosion when a high-voltage circuit breaker at an asphalt plant shorted out has secured a $13.9 million settlement in his suit against the plant's owner and operator.

- While eating his lunch in the plant's electrical room, the technician suddenly saw sparks and detected the odor of ozone gas, prompting him to shove his co-worker out of the room.
- Before the Technician could escape, the high-voltage circuit breaker exploded with an intense heat that caused a plasma blast, meaning that the metal components had vaporized.
- In the suit against the company, the plaintiff's lawyers alleged that the accident was the result of a **failure to perform routine maintenance.**
- The company's chief electrician admitted in his deposition that the maintenance was not performed and testified that **the reason was financial**, because any work on the electrical system would force "downtime" at the plant.

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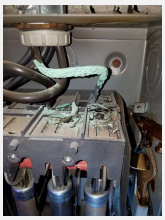
Infrared Thermal Scans

- Required at least yearly by NFPA-70B
- Intervals depend on equipment type and condition
- Identifies hot spots and issues prior to failure.



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IR Window Installation

- Removes the arc flash and shock hazards
- Scan medium voltage or high arc flash equipment while energized
- Scan more frequently during normal pm routes

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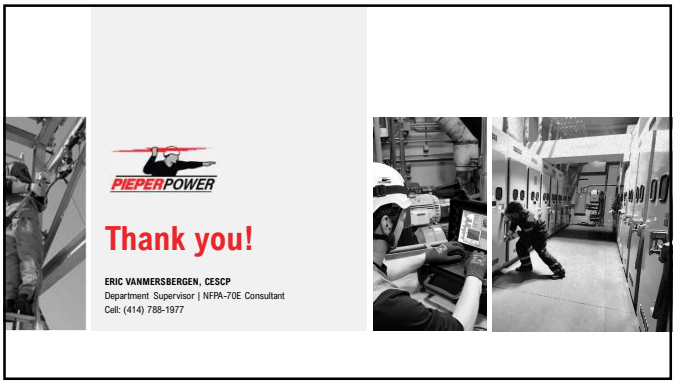
PIEPERPOWER
Thank you!
ERIC VANMERSBERGEN, CESCP
Department Supervisor | NFPA-70E Consultant
Cell: (414) 788-1977

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